


FORESTENERGY PROGRAMME

# Whole-tree harvesting of conifer first thinnings for energy wood chip production

*Pieter D. Kofman*[1] *and Tom Kent* [2]

## Introduction

Harvesting wood fuel from forest thinnings differs from other types of assortments in that the whole tree is suitable as a fuel. The branches and tree tops will produce suitable material for chipping, only the leaves or needles are not suitable. Any wood that is to be used for energy should be seasoned before it is chipped, as the energy content of wood chips is directly related to moisture content (MC). Seasoning the whole trees in the stand, before chipping, utilises the ambient climate to remove moisture and does not require investment in dedicated storage. As the tree dries, the leaves will desiccate and fall off. This has the added advantage that the nutrients, which are mainly found in the needles, stay in the forest. Forest sites vary greatly in local climate, exposure and humidity, so the time required to season timber before chipping will vary.

The whole-tree thinning method, which is widely used in Denmark, is usually a two-stage approach: during the first intervention, one line in seven is felled by chainsaw, left for at least one summer for drying, and then chipped with a terrain chipper (tested at ForestEnergy sites in 2006, 2007 and 2008). During the second intervention, a selection thinning is carried out with a feller-buncher (tested in 2006). The trees are lifted into the rack and left there in small bunches for summer drying. The trees are then chipped by a terrain chipper.

Thinning is carried out at an early stage of stand development, and some years before what would be the usual thinning age in Ireland. In this way the growth of the stand is concentrated on fewer and better trees, so that by the time of the second thinning, a few years later, more small sawlog will be available. Currently in Ireland, first thinning is only carried out when the trees are of suitable size to yield sufficient quantities of boxwood, to cover the cost of the intervention. Delayed first thinning reduces productivity, long-term profitability, main crop quality and increases the risk of windthrow. Whole-tree first thinning yields more material earlier in the rotation.

### ForestEnergy Programme 2006-08

The COFORD ForestEnergy programme has the objective of securing marketable wood fuel of acceptable moisture content for sale as wood chip, firewood and other wood fuels, to support the development of the renewable wood energy sector in Ireland. The programme achieved this through commercial scale demonstrations of forest harvesting supply chains for wood energy on 15 forest sites (Figure 1). At each site the supply chain productivity, fuel quality and delivered energy cost of each system was assessed. Different storage options and seasoning schedules over one and two summer seasons were investigated. Public demonstrations of machinery and methods were held each year of the programme.


**Conifer sites**
1. Abbeyfeale, Co Limerick
2. Ballybofey, Co Donegal
3. Bweeng, Co Cork
4. Croaghrimcarra, Co Mayo
5. Foilagohig, Co Cork
6. Frenchpark, Co Roscommon
7. Kilbrin, Co Cork
8. Swan, Co Laois
9. Woodberry, Co Galway

**Broadleaf sites**
10. Dovea, Co Tipperary
11. Manseragh, Co Tipperary
12. Mullinavat, Co Kilkenny
13. Portlaw, Co Waterford
14. Stradbally, Co Laois

**Cutaway peat site**
15. Boora, Co Offaly

**Long-term storage trial site**
16. Rochfortbridge, Co Westmeath

Figure 1: Location of the ForestEnergy programme trial sites.

COFORD
Arena House, Arena Road,
Sandyford, Dublin 18, Ireland
Telephone: +353 1 2130725
Email: info@coford.ie
http://www.coford.ie

[1] *Danish Forestry Extension, Senior Consultant Wood for Energy. Email: woodenergy@gmail.com.*
[2] *Waterford Institute of Technology. Email: tkent@wit.ie.*

The study of the suitability of this method in Ireland was a key element of the COFORD-funded ForestEnergy programme, as whole-tree thinning is successfully used elsewhere for wood fuel production. The whole-tree method has advantages over standard thinning, since it ensures a high volume of wood fuel is produced per unit area, as tops and branches and small trees are chipped. This method also has a positive impact on stand quality since most poor quality trees can be removed from the stand during the selective thinning intervention. Poor quality trees include small trees, double stems, damaged trees, unwanted species, oversized, badly formed trees etc. Stands thinned in this way will have an even spacing. A disadvantage is that there is no brash mat for the machines to operate on; however, some felled trees can be sacrificed and put under the wheels where required.

Machines to carry out this job were not yet available in Ireland at the time of the trials, so all machines were transported from Denmark, with experienced crews, to perform all operations. At the time of writing one terrain going tractor-mounted chipper is now operating in Ireland.

## Differences between the years

In 2006, when the method was fully used for the first time to produce wood chip for energy, three stands at Frenchpark, Swan and Kilbrin were selected for their good ground conditions: terrain had to be found that could bear heavy machinery without problems. The results were very positive, but were not necessarily representative of the range of softer or steeper terrain found in Irish conifer plantations. It was also found that the trees did not dry enough in one summer to make suitable fuel for those boilers which require wood fuel with less than 35% moisture content.

In 2007, therefore, five further stands were selected that were either on soft ground or had some slope: Abbeyfeale, Ballybofey, Bweeng, Toormakeady and Woodberry. Line thinning by chainsaw was carried out in spring 2007. The felled trees were left to season over one or two summers to investigate the potential for reducing moisture content further. Half of the felled area on each site was chipped in the autumn of 2007, the other half in autumn 2008, except for Bweeng where all the material was chipped in 2007 as the site was quite small.

Different crews operated the Silvatec chipper and chip forwarder each year of the trials, but all were experienced personnel. The Silvatec machines used in 2006 and 2007 were similar, while the chipper machine used in 2008 was equipped with band tracks. After a few days of operation, the chip forwarder was also equipped with band tracks for the 2008 trials.

## Machines

In all stands the line trees were felled by chainsaw. Different chainsaw operators were employed on different sites, so instructions had to be given and work monitored at each site. The trees were felled so that each one lay along the line in the same direction.

Felling trees in the line by chainsaw.

Silvatec feller-buncher in operation.

The feller-buncher was used in 2006 to carry out selection thinning between the racks. The machine used was a three-axled Silvatec base machine, equipped with a parallelogram crane and a Silvatec felling head. The felling head has a stabilising cylinder that enables it to take out trees in a standing position. It has no feed rollers or delimbing knives, but has a set of accumulating arms so that more than one tree in a cycle can be felled and lifted out to the rack. This increases productivity when harvesting small trees.

The Silvatec chipper is a self-propelled machine, developed for chipping trees inside the stand in confined spaces. In Denmark 500 mm wide tyres are used, but for operations in Ireland these were replaced by wider, 600 mm tyres, to increase flotation. In the 2008 chipping trials the wider tyres were complemented with band tracks.

The front-mounted chipper can handle trees up to 35 cm in diameter. Chips are blown to the rear of the machine into a 15–17 $m^3$ storage tank, which can be lifted high in the air to unload the chips in the chip forwarder.

The chip forwarders were also equipped with wider tyres than would usually be used in Denmark. In 2008, after a few days of trials without band tracks, it was decided to mount them on the chip forwarder to increase flotation and traction. The chip forwarder transports the chips from inside the stand to the roadside. The wood chips can be tipped into containers or other vehicles for road transport.

In 2006, a tractor-mounted terrain chipper was included in the trials. This was a TP280 disk chipper mounted on a large Valmet tractor, which was permanently reversed. A hitch was attached to the tractor nose, so the machine could tow a high tipping trailer. Unlike the Silvatec chipper, this machine must travel to and from the stand to unload at the roadside.

In 2006 the chips were transferred to tractor-trailers or dumped on the ground and reloaded onto walking-floor trucks. Only in 2007 was it possible to demonstrate the use of container lorries for road transportation of woodchip. This integrated approach is common in Denmark but is not yet widespread in Ireland. Two container trucks were taken from Denmark to Ireland to study the complete chain. In 2008, the whole-tree chip was again dumped at roadside and reloaded into walking-floor lorries.

Chipping the line trees by Silvatec terrain chipper. Note the bandtracks on the wheels.

TP280 tractor-mounted front-fed chipper in line thinning. The trees are not yet completely dead.

Chip forwarder coming to the road with a load of chips. Note the bandtracks.

## Results

Averages for each of the three years of the programme are presented. Full data for each year will be presented in the final report on ForestEnergy.

Table 1 lists the results for 2006, 2007 and 2008 for whole trees that were felled either by chainsaw (line thinning) or by feller-buncher (from selection thinning) and chipped either by Silvatec or TP tractor terrain chippers.

The average total production cost of woodchip to roadside ranged from €14.31/$m^{3\ sb}$ to €26.80/$m^{3\ sb}$. When the moisture content is factored in, the production cost per unit of wood energy ranged from €2.04/GJ to €4.25/GJ. There are large differences between the years in the total production cost per $m^3$ solid biomass. In 2006 the costs were lowest due to the high productivity of both the felling and the chipping. The costs increased in 2007 as productivities fell, partly due to the soft terrain, and production cost improved again in 2008 as productivity came back up because the machines were equipped with band tracks to cope with softer ground.

As can be seen from Table 1 there was a lot of variation in the felling costs for the chainsaw operations. The differences between individual sites are even larger but have

### System productivity

All operations were time studied, and the net productive time was recorded. Net productive time excludes all interruptions and, in order to reflect a normal working day, allowances were added to obtain work place time. Allowances include rest breaks, small repairs and other normal interruptions, but exclude events such as major breakdowns and bogging. By adding 3% allowances for machine work, and 70% for chainsaw felling, productive machine hours (pmh) was obtained.

### Units

In all cases the volume of loose chips ($m^{3\ lv}$) from the chippers was converted to $m^3$ solid biomass ($m^{3\ sb}$) by using a conservative ratio: 1 $m^{3\ lv}$= 0.33 $m^{3\ sb.}$ All production figures and costs are expressed in $m^{3\ sb}$/pmh or €/$m^{3\ sb}$. With the measured moisture content of the chips at the time of chipping, the energy content of the chips is expressed in GJ/$m^{3\ sb}$ and the final cost is expressed in €/GJ.

Table 1: Overview of productivity and costs of the whole-tree method with terrain chipping in conifers.

| Year | 2006 | 2006 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|
| Number of sites | 3 | 3 | 3 | 4 | 4 |
| Thinning type | Line | Line | Selection | Line | Line |
| Thinning method | Chainsaw | Chainsaw | Feller-buncher | Chainsaw | Chainsaw |
| Felling productivity ($m^3$/pmh) | 8.49 | 8.49 | 14.61 | 5.9 | 5.9 |
| Chipping machine | Silvatec | TP270 Tractor | Silvatec | Silvatec | Silvatec |
| Chipping productivity ($m^3$/pmh) | 27.43 | 6.73 | 25.17 | 13.8 | 16.4 |
| Chainsaw cost @ €25/pmh (€/$m^{3\ sb}$) | € 3.42 | € 3.42 | | € 4.80 | € 4.80 |
| Feller-buncher cost @ €100/pmh (€/$m^{3\ sb}$) | | | € 7.00 | | |
| Silvatec chipper cost @ €300/pmh (€/$m^{3\ sb}$) | € 10.89 | | € 11.91 | € 22.00 | € 18.55 |
| TP tractor chipper cost @ €100/pmh (€/$m^{3\ sb}$) | | € 19.92 | | | |
| Total cost (€/$m^{3\ sb}$) | € 14.31 | € 23.34 | € 18.91 | € 26.80 | € 23.35 |
| Average energy content (GJ/$m^3$) at seasoned MC | 7.00 | 6.66 | 6.78 | 6.30 | 6.80 |
| Average energy cost to roadside (€/GJ)* | € 2.04 | € 3.50 | € 2.79 | € 4.25 | € 3.43 |

* The moisture content of the harvested chips varied from 43 to 48% after two seasons of drying.

been evened out by averaging. This variation was due to the different levels of competence amongst chainsaw operators and the variation in mean tree size between different sites. The felling costs for 2007 and 2008 are the same, because the trees were all felled at the same time in 2007. The felling of the trees from the selection thinning with the feller-buncher was much more productive than the felling of the line trees by chainsaw, but the hourly costs of the machine are higher also. No study was made on chainsaw felling in selection thinning.

There was also a very large variation in the productivity of the Silvatec chipper. In 2006 the stands had been selected to get reasonable to good bearing capacity on the ground, in order to successfully demonstrate the Silvatec chipper and forwarder operation. This had a positive impact on the capability of the machine. The terrain chipping productivity in 2007 was reduced as sites with low bearing capacity were worked, and the fact that both the chipper and the chip forwarder were on wheels without band tracks. The productivity in 2008, on the same sites, improved because the addition of band tracks increased machine mobility. Despite a higher unit cost, the Silvatec system was cheaper than the TP 280 tractor when trialled on the same sites, due to the greater productivity achieved by the former.

An estimate of the delivered cost of wood energy to the end user can be generated by including some assumptions on the whole chain costs.

The total harvesting cost at the roadside delivered in containers would be in the order of €2.75 to €5 per GJ. If the forest owner was paid €5 per $m^3$ solid biomass (stumpage), then that would add €0.70 to the cost. The cost of road transport over a distance of 50 km would be €1.50, giving a total delivered-in price at the plant of €4.66 to €7.09 per GJ, which includes a 10% overhead for the woodfuel trader. Typical component costs to arrive at a delivered-in price are summarised as follows:

| | |
|---|---|
| Stumpage (€5/$m^{3\ sb}$) €/GJ | € 0.70 |
| Chipping operation €/GJ | € 2.04 - € 4.25 |
| Road transport 50 km €/GJ | € 1.50 |
| Trader's allowance 10% €/GJ | € 0.42 - € 0.64 |
| Total delivered-in cost €/GJ | € 4.66 - € 7.09 |

## Conclusions

Total delivered-in costs of this type of wood fuel at a major consumer that can handle relatively wet fuel would be in the order of €4.66 - €7.09 per GJ or roughly €44-67 per tonne at 45% moisture content.

First thinning can be carried out economically at an earlier age of the stand, thus reducing the risk of windthrow and concentrating the growth of the stand on fewer and better trees.

Using the whole-tree method in first thinning will increase the amount of biomass being removed compared to the traditional shortwood method, by an average of around 50%. This means that the forest owner will benefit more from this method than from any other. In addition, production costs are spread over a greater amount of harvested woodfuel.

Seasoning whole trees at the stump ensures that leaves and needles, which contain most of the nutrients in harvested material, have time to decay and fall, maintaining forest soil fertility. Also, the wood dries efficiently at the stump as the leaves transpire water from the stem. On the other hand, in trials over both one and two summer seasons, it was not possible to achieve the moisture content necessary for supplying dry fuel boilers.

The fact that a brash mat is not created for machinery is a major concern in whole-tree thinning in Ireland. Ground bearing capacity was a problem each year, and not only for the chipping operation. In some cases machines got bogged down. However, problems were reduced once band tracks were used. At Toormakeady, on a fairly steep slope, the Silvatec chipper worked its way downhill, crossed the drain at the bottom of the field and came up the next rack. The chip forwarder followed the chipper several times and came back up every time with a full load.

Selective thinning by chainsaw was not trialled as it would be extremely hard work for the chainsaw operator to drag every tree down through the canopy. The productivity of the chipper would be hampered substantially by chainsaw felling the selection thinning. The trees are presented in a herringbone pattern, which means that the chipper has to wait until the whole tree has been chipped before it can move forward again. With the trees felled by the feller-buncher, the machine can move forward almost continuously.

The feller-buncher is a good machine to carry out selection thinning. It can accumulate two or more trees, before they are lifted out of the area next to the rack and laid down in the rack in a roof tile fashion. Felling costs with the feller-buncher were higher than those of the chainsaw felling of the rack trees, but that is an unfair comparison. Trees in the rack can fall when pushed over by the chainsaw operator, but that is certainly not the case in chainsaw felling of a selection thinning. The chipping productivity after the feller-buncher was slightly lower than that of chipping the rack trees. This is caused by the smaller average size of trees from the selection thinning. Even so, the production cost of €2.79 per GJ from the selection thinning was less than the production cost of chipping line trees with the tractor-mounted chipper.